Measuring Bedload with Geophones, Navisence River

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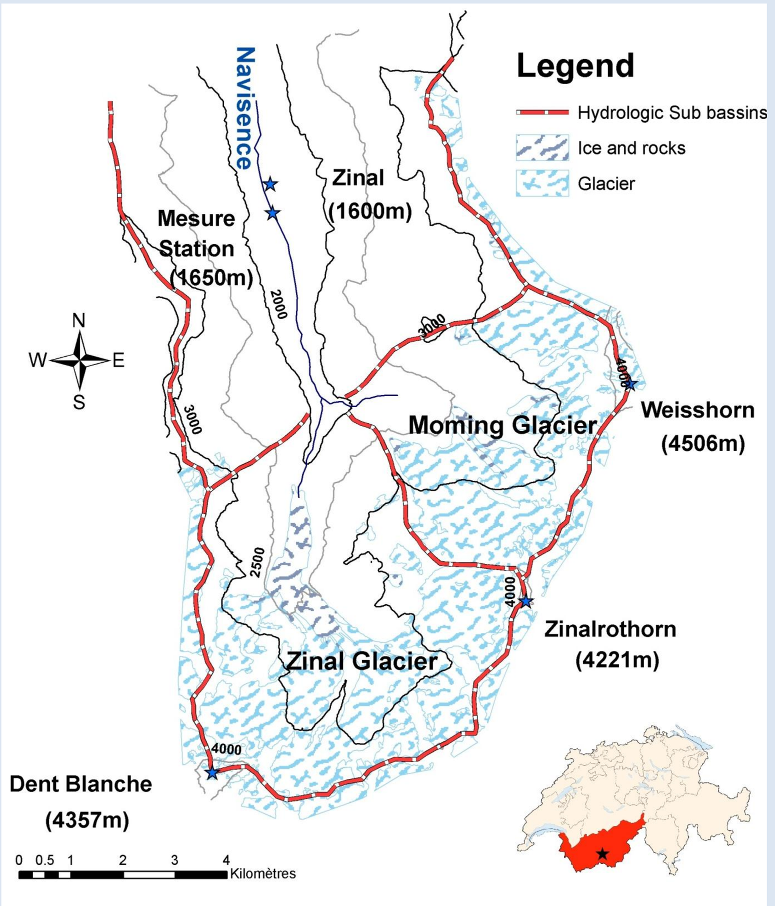

Fig 1 : Navisence catchement

Presentation

The bedload transport (and arrest) determines in river cross-sections the remaining available space for the water. In the Alps, where the slope of rivers are steep, no floods are occurring without bedload. Thus, a good knowledge of this phenomena is crucial for the planners confronted with rivers. Very few field data acquired in this context exist. This poster presents a indirect bedload monitoring by geophones and discusses results after the first year results.

The Navisence stream is situated in the Center Wallis Alp. The catchement bassin (Fig 1) is subdivide into two main heavily glacierized sub-bassins : the Zinal glacier catchment (35.5km^2) and, the Arpitetta catchment (19.5 km^2). Some smaller catchments with glacier and permafrost features are drained toward the measurement station too. Finally a surface of 80 km^2 flow through the station at the elevation of 1650m.

The installation (Fig 2A), inspired by Rickenman 2008, consists of a concrete section equipped with a pressure gauge (estimation of water level), a conductivimeter and 12 plates of metal covering the whole wetted width, each one coupled with a geophone (estimation of sediments impacts).

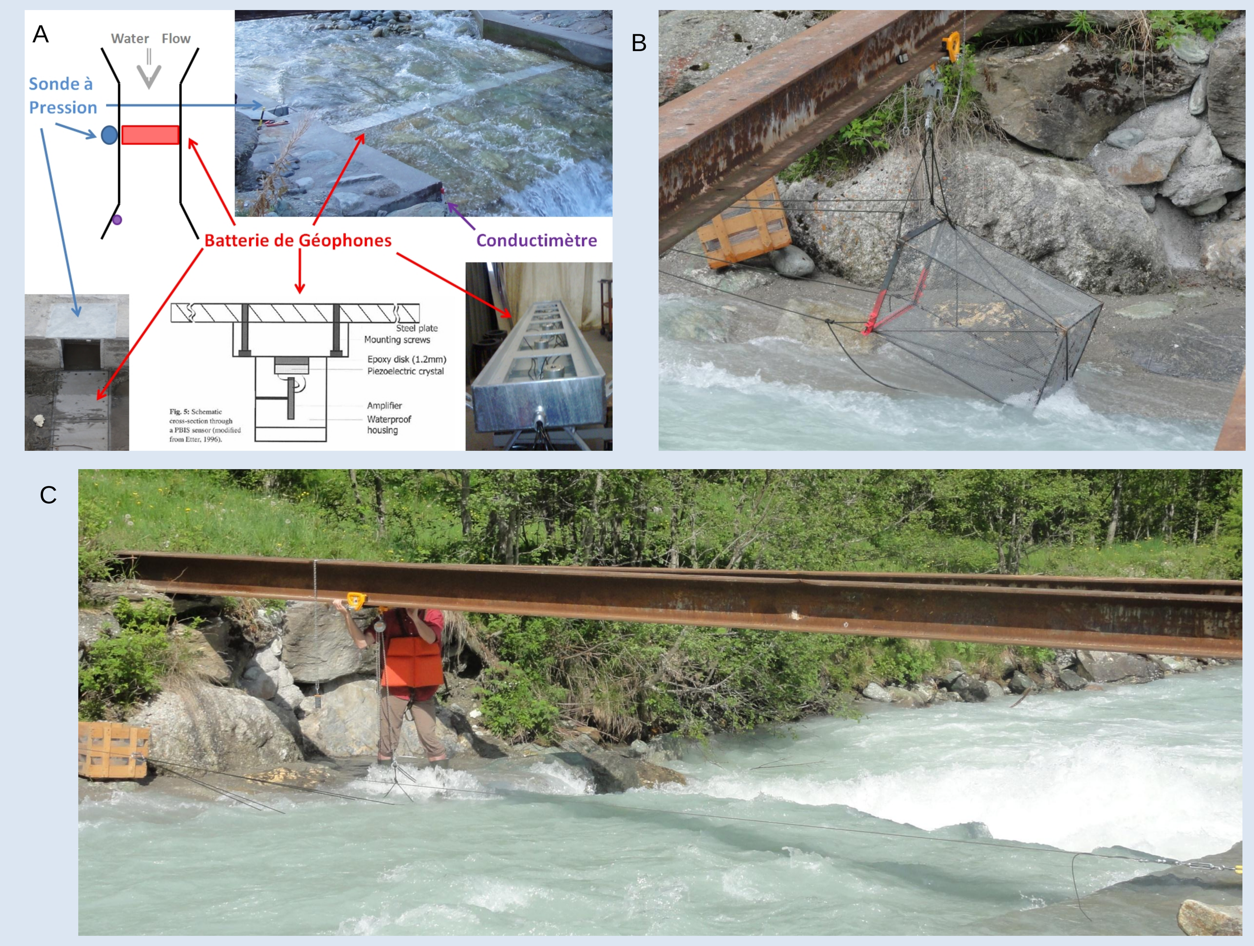

Fig 2 : A) Gauging station B) Sediment trap C)Sampling test

Geophone Calibration

The geophones allow estimating the vibrations generated by the sediments. To be useful it should be converted into a flux of rock debris through the cross-section. For this purpose we immerse a sediments trap (Fig 2B) immediately downstream a geophone (i.e. a 50 cm width plate of metal). As the flow level increase with the season, a system of winches and cables is necessary to manage the trap. For this first season of calibration we chose to focus on a single geophone located on the left bank. The proximity of the bank ensures better control of the position of the cage, and greater ease of handling. The sediment trap is 1 m in hollowness with a square cross-section of 0.5 m. It is surrounded by a metallic grid mesh with aperture of 8 mm. Depending on the discharge (solid and liquid), immersion lasts between 2 and 5 minutes.

The first results are very encouraging. With a correlation coefficient greater than 79%, the relationship between the number of pulses and the sediment weight captured (on a sample clipped to particle above 24 mm in diameter) is very good. This correlation coefficient go down to 74% for the whole sample (i.e. sediment >8 mm in diameter). It can be explained by the difficulty for the geophones to record low impact.

We will use later in this document two calibration equations, with the following assumptions :
- each geophone follows the same calibration equation;
- no bedload is effective, if no pulse is recorded.

Our calibration is valid only for low to medium flow rates, i.e. for a set ranging from 0 to 100 pulses/s. It should be said that the major summer floods recorded maximum up to 2'000 pulses/s.

Eq 1 : $M = 1.0375 * (1 + P)^{1.2625}$
$R^2 = 0.7407$

Eq 2 : $M = 1.25*P^2+219.78*P$
$R^2 = 0.73621$

The two calibration equations (according to the size of the sample (Fig 3)) range over the same number of pulse/s and should be extrapolated for higher rate of vibrations. In this domain the calibration equations offer strong differences. At the time of writing, lacking of data during high floods, we consider that these laws are applicable for large solid discharge too.

M : Sediment weigth (g)
P : Nomber of pulses recorded by the geophone

To test these assumptions, a second season of calibration will be necessary in order to:
- better specify the critical drag rate by focusing on small flows, with a finer net enabling to trap smaller particles ;
- calibrate a larger set of geophones to study the influence of micro-topography immediately upstream of the bed ;
- elaborate a new device to collect information during large floods. Indeed, volumes related to these flow peaks are very important with a marked influence on the bed geometry.

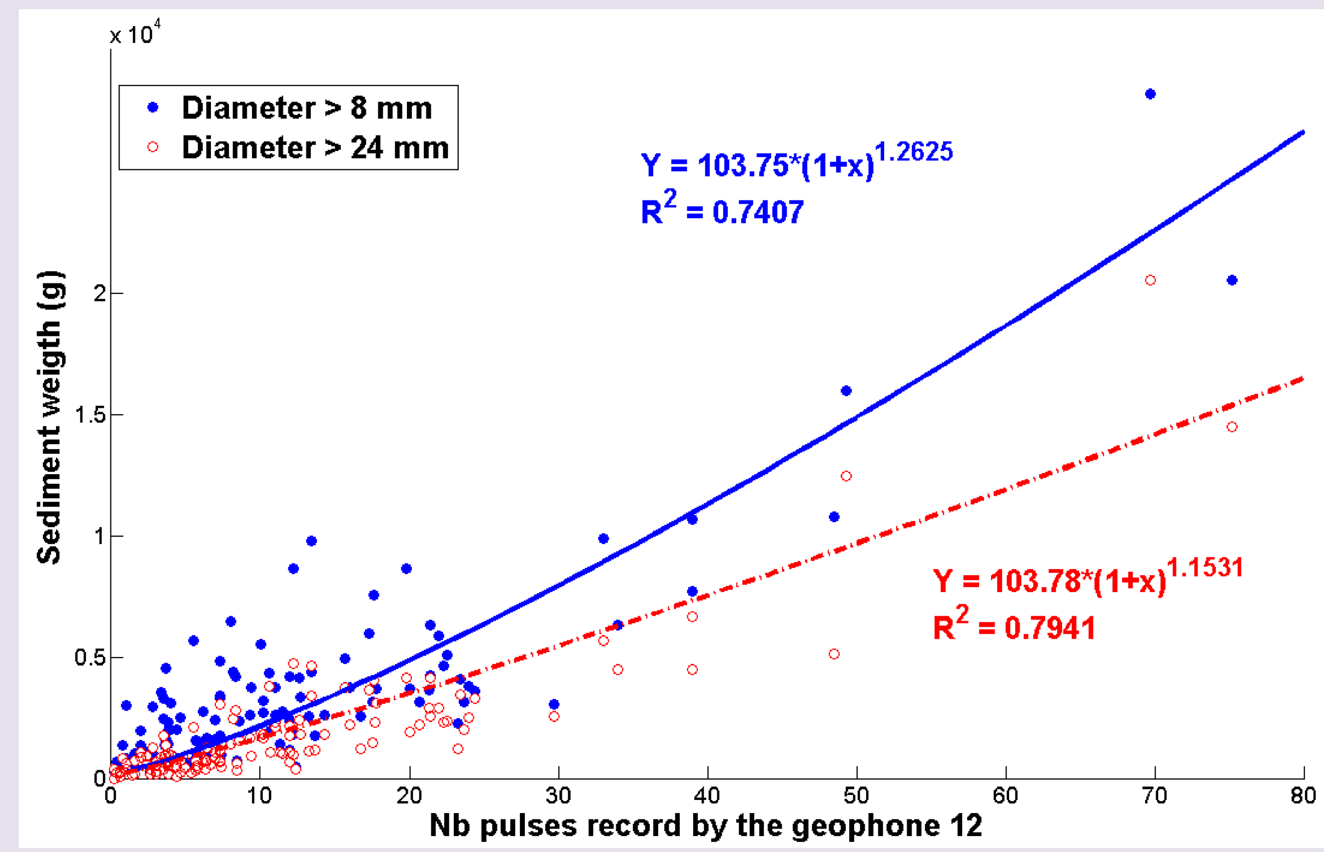

Fig 3 : calibration curve with equation type $y = a(1+x)^b$ (for plate 12)

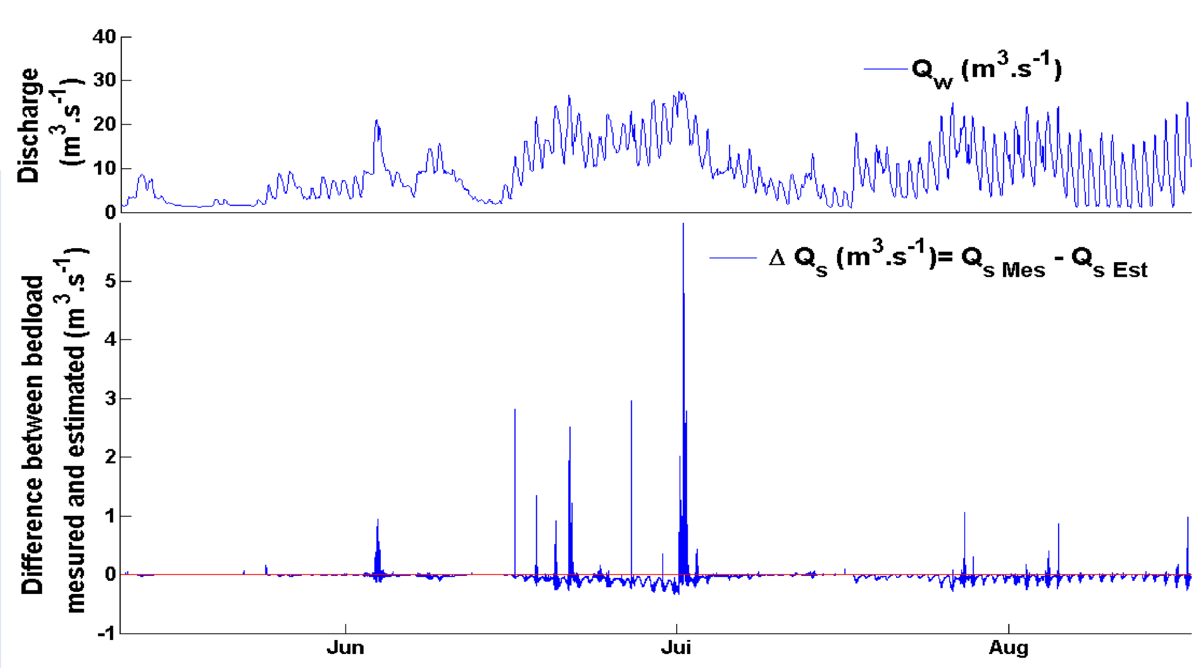

Fig 4 :Year 2012 top, Discharge, bottom, Difference between estimated (Recking in press) and mesured bedload

Application

We compare the volume of sediments measured by the geophones using our calibration equations with the volumes estimated by hydraulic modelling using formula from literature. Results show that classic formulas (Rickenmann 1991, Recking 2008, Smart and Jäggi 1983) provide volume two orders of magnitude above the measured one.

Finally we use the new formula developed by Recking (in press) for which the estimated annual volume of bedload are of the same order of magnitude than the one measured. As our two formulas seem to underestimate the overall bedload, it can partly explain the difference.

However, this annual sum hides significant differences in the estimated timeframe of bedload event. Hydraulic formula tend to overestimate the bedload at low flow rates (resulting in negative value on the lower diagram (Fig 4)). Unlike during high flows transport volume seems significantly higher than the computed volume (probably due to extrapolation with calibration equation).

We can also observe that the volume available seems to be related to the timing since the last events (Yager 2012)

2011

$\sum_{year} Q_{SG\ (Eq\ 1)} = 4050\ m^3$

$\sum_{year} Q_{SG\ (Eq\ 2)} = 5193\ m^3$

$\sum_{year} Q_{S\ Recking\ 2012} = 3300\ m^3$

$\sum_{year} Q_{w} = 74\ 10^6\ m^3$

2012

$\sum_{year} Q_{SG\ (Eq\ 1)} = 3700\ m^3$

$\sum_{year} Q_{SG\ (Eq\ 2)} = 5550\ m^3$

$\sum_{year} Q_{S\ Recking\ 2012} = 4950\ m^3$

$\sum_{year} Q_{w} = 96\ 10^6\ m^3$

Fun with statistics …

The measurement made since one and a half year shows an univoque link between hydraulic rate and solid discharge could not explain the observed data. A close look to the data let us often observe a decreasing rate of bedload during successive floods. Everything happens as if the geomorphological availability of sediments balances the transported quantities deduced from pure hydraulic estimation. To investigate that we calculate for each day :
- The total volume of water flowing through the station, Q_w
- The total volume of sediment crossing the station, Q_{SG}
- The difference between the bedload measured and the one estimated by the hydraulic formula for the previous day before . It is an index which expresses how the amount of effective bedload is close to the transport capacity of water. In other word it is an index of the sediment availability. It is computed for the day before, D_{-1} to fifth day before, D_{-5}.

Comparing these data in a Principal Component Analysis (Fig 5) show that :
- For the years 2011 and 2012, the bedload is directly influenced by the liquid flow ;
- In 2011, it is anti-correlated with the behavior observed in D_{-1} ;
- In 2012, this anti-correlation is shifted more or less to the previous 12 hours.

We are facing a loading/unloading of sediment with a specific latency. Indeed behavior at time t depends on the difference between the current bedload and that expected at time t_{-1}. This latency can be regarded as a kind of system's memory. The change in correlation between 2011 and 2012 (corresponding approximately to a latency minored to 12h) can be related to the operations in a gravel pit, upstream the station (Eaton & Church 2004).

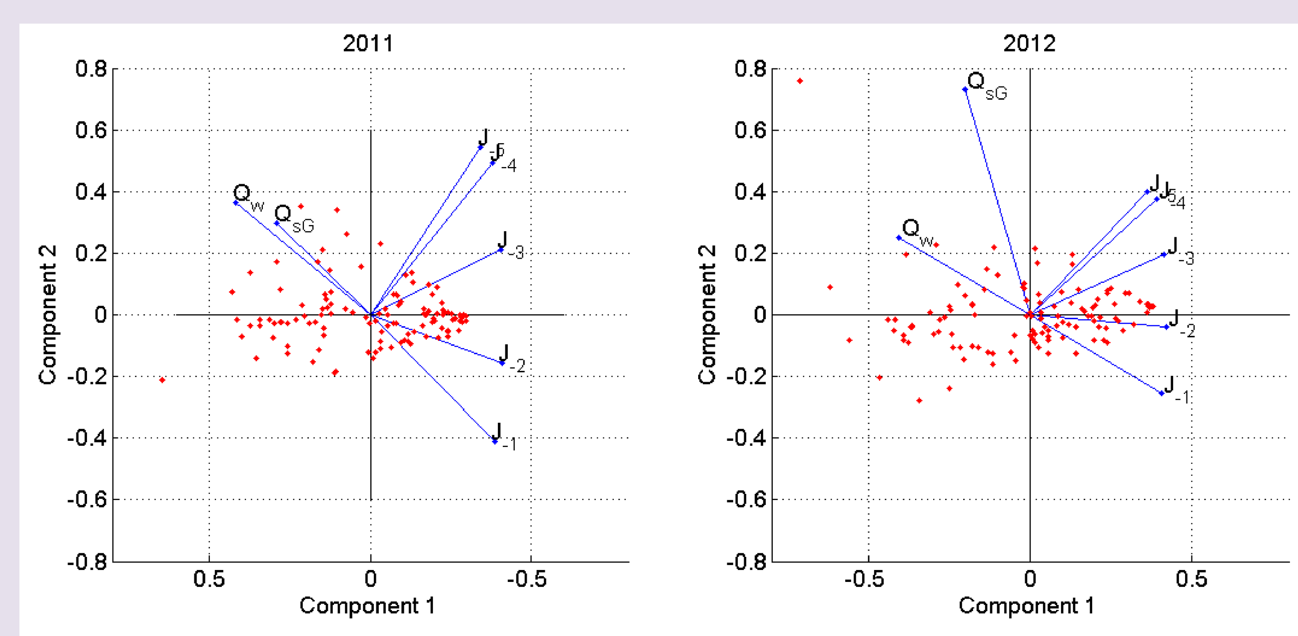

Fig 5 : Principal Composant Analysis diagram

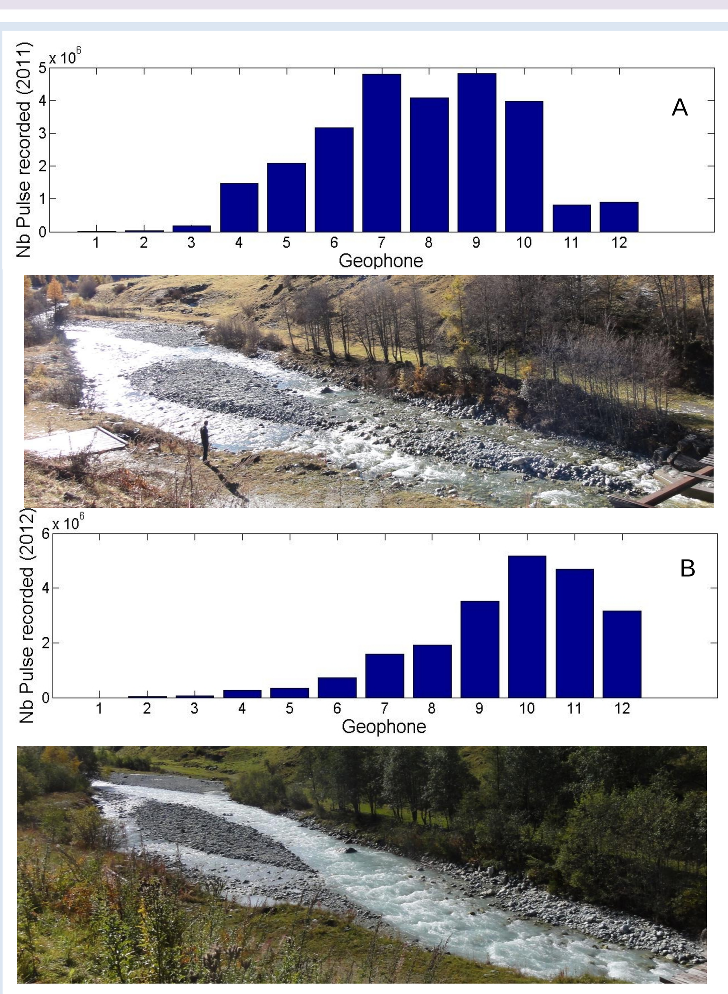

Fig 6 : Riverbed upstream of the section and sum of pulses recorded per geophone for A) 2011 B) 2012

Geomorphology

The observed distribution of pulse shows that only in a narrow part of the riverbed undergo bedload (Fig 6). It is similar to the results obtained by Rickenman and coauthors (2006). It implies that the bedload should not be averaged to the whole cross-section.

After floods which have produced changes in the margins of the bed – but only slight changes in the deepest section – the lateral repartition of the pulses do not evolve significantly. The apparent relation to the geometry of the section may be of importance for studying critical drag forces .

Conclusion and Perspectives

Calibration performed allows us to obtain first estimates of sediments volumes. These transported volumes seem to be best approached by the new equation given by Recking (in press). However some work is still needed to refine the calibration curve, especially :
- taking into account of the finer particles;
- considering the effect of the micro topography near the plate;
- supplementing the relation with measure during intense floods.

The influence of the previous bedload discharge may be a track for going to an operational prevision. To consolidate our results from an hydraulic point of view as well as for prevision model, more data is needed.

Adding a spatial dimension to the sediment transported, for example by using of RFIDs should allow us to better constraint the "memory" of our system.

References

Eaton, B. C. and M. Church (2004), A graded stream response relation for bed load–dominated streams, *J. Geophys. Res.*, 109, F03011, doi:10.1029/2003JF000062.

Smart, G. M., and M. N. R. Jaeggi (1983), "Sediment transport on steep slopes", 89-191 pp.,Mitteilungen n°64, *Der Versuchsanstalt fuer Wasserbau, Hydrologie und Glaziologie*, Eidg. Techn.Hochschule Zuerich, Zurich.

Recking, A. (in press). "Influence of sediment supply on mountain streams bedload transport", *Geomorphology*, GEOMOR-04056

Recking, A. (in press). "A simple method for calculating reach-averaged bedload transport." *Journal of Hydraulic Engineering*, doi: 10.1061/(ASCE)HY.1943-7900.0000653.

Rickenmann, D. (1991), "Hyperconcentrated flow and sediment transport at steep slopes, " *Journal of Hydraulic Engineering (ASCE), 117, 1419-1439.*

Rickenman, D.,Chiari, M., Friedl, K. (2006), "SETRAC - A Sediment routing model for steep torrent channels", *Geophysical Research Abstracts*, Vol. 8, 03396, 2006

Rickenmann, D., McArdell B.W. (2008). "Calibration of piezoelectric bedload impact sensors in the Pitzbach moutain stream" *Geodinamica Acta*, 21, 35-52

Rickenmann, D., and Recking, A. (2011). "Evaluation of flow resistance in gravel-bed rivers through a large field dataset." *Water Resources Research*, 47, 1-23. doi:10.1029/2010WR009793

Yager, E. M., J. M. Turowski, D. Rickenmann, and B. W. McArdell (2012), Sediment supply, grain protrusion, and bedload transport in mountain streams, *Geophys. Res. Lett.*, 39, L10402, doi:10.1029/2012GL051654.

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